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REPORT NO. R-1189

TIPPED TRUNCATED OGIVAL AP SHOT - PENETRATION PERFORMANCE vs BODY AND TIP HARDNESS

BY

H. E. Fetzinger and J. R. Kymer

PROJECT TA1-5002

PITMAN-DUNN LABORATORIES
FRANKFORD ARSENAL
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REPORT R-1189

TIPPED TRUNCATED OGIVAL AP SHOT - PENETRATION PERFORMANCE VS BODY AND TIP HARDNESS

Project TA1-5002

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OBJECT

To investigate the effect of tipped truncated shot body and tip hardness upon penetration performance.

SUMMARY

Penetration performance was compared for tipped truncated ogival 20 mm AP T33 shot having steel bodies of 66 Rc, 63 Rc (conventional) and 55 Rc hardnesses. Targets investigated included: 1 1/8-inch (1.43 caliber) plate at 45° obliquity; one-inch (1.27 caliber) plate at 45° and 55° obliquities; 7/8-inch (1.11 caliber) plate at 30°, 55°, and 60° obliquities; and 3/4-inch (0.95 caliber) plate at 60° obliquity. The effect of tip hardness upon ballistic performance of tipped truncated ogival (FAPT)* shot was also investigated. Steel tips of 59 to 61 and 43 to 45 Rockwell C hardness, attached to truncated T33 shot bodies, were compared with aluminum tips of 120 Brinell hardness. Test conditions were: one-inch (1.27 caliber), 7/8-inch (1.11 caliber), 3/4-inch (0.95 caliber), and 5/8-inch (0.79 caliber) plate set at 30°, 55°, 60°, and 60° obliquities, respectively. All tips in both investigations were attached to the shot bodies with Chrysler Cycleweld C-14 plastic cement.

The FAPT shot having bodies of conventional hardness (63 Rc) were greatly superior to those having bodies of lower hardness (55 Rc). There was no consistent significant difference in penetration performance between tipped shot bodies of 63 and 66 Rockwell C hardnesses. Results of 76 mm AP T166E2 (tipped) firings with shot bodies of very high (65 to 66 Rc), conventional (60 to 61 Rc), and lower (57 to 58 Rc) hardnesses are also summarized in this report. The targets were two-inch (0.67 caliber) homogeneous plate at 60° obliquity and four-inch (1.33 caliber) homogeneous plate at 30° obliquity. At the 76 mm scale, FAPT shot bodies of 60 to 61 Rc hardness were only slightly superior to those of 57 to 58 Rc hardness, but were superior by as much as 200 fps to those of 65 to 66 Rc hardness. At both scales, therefore, these tests indicate that the hardness of FAPT shot bodies should be neither higher nor lower than conventional.

The performance of FAPT shot having steel tips of 59 to 61 Rc hardness was similar to those of 43 to 45 Rc hardness. Aluminum tipped shot were almost as effective as the steel tipped shot against 5/8-inch (0.79 caliber) plate at 60° obliquity, but were greatly inferior to the steel tipped shot against one-inch (1.27 caliber) plate at 30° obliquity.

AUTHORIZATION

OO 400.112/22325, ORDTA, FA 471.1/1557-1, 10 December 1945

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*This notation is not an official Ordnance designation but has been used for easy reference. This designates a flat nose AP shot having a protective tip.

INTRODUCTION

The chronological development of the truncated ogival (FAP)* and tipped truncated ogival (FAPT)* shot is described in Reference 1. A previous investigation at the 20 mm scale has compared the armor penetration performance of these shot types with models of the 90 mm AP M318 (T33) conventional ogival monobloc shot over a wide range of target conditions. A report,[2] including a brief summary of the development of the FAPT type, described the results of this investigation. The FAPT shot were equal to or superior to the AP for almost all of the target conditions investigated. Exceptions were heavy plate at 0° obliquity and thin plate at intermediate obliquity. FAPT shot were superior to the AP against armor up to and including 7/8-inch (1.11 caliber) thickness at 55° and 5/8-inch (0.79 caliber) at 70° obliquity. For the more difficult high obliquity targets, the FAPT and AP types appeared to be equal in performance. Conventional AP shot were best in the limited region of very heavy plate at very low obliquity. The FAPT shot were superior to the FAP when the latter shattered. However, when both types remained intact, the FAPT were inferior to the FAP. Some of these 20 mm penetration results have been confirmed by limited firings of truncated 75 mm AP M338 (T148) shot, truncated conical 120 mm AP T116E2 shot and tipped truncated 76 mm AP T166 shot.

Since the 20 mm and most of the full caliber firings were conducted with shot bodies and tips having conventional hardness (61 to 63 Rc), the subject firings were conducted to determine how FAPT shot with bodies and tips of higher and lower hardnesses would compare ballistically. A summary of limited 76 mm AP T166E2 (tipped) firings with shot bodies of very high, conventional, and lower hardnesses is also included in this report. The results of firings with 20 mm conventional ogival AP T33 shot of various hardnesses are described in Reference 3.

MATERIALS

Shot and Tips

Design. Conventional ogival 20 mm AP T33 shot were truncated to a flat diameter of 0.650 inch. The steel and the aluminum tips had the shape of the AP ogive with a flat diameter of 0.720 inch. The diameter of the tip flat was larger than that of the body flat so that it would overhang the body flat and protect its biting edge. All

*These notations are not official Ordnance designations but have been used for easy reference.

[1]H. W. Euker and C. W. Curtis, "Design of Armor Piercing Projectiles for High Angle Attack," Frankford Arsenal Report R-1070, June 1952.

[2]J. R. Kymer and H. E. Fatzinger, "Solid Steel AP Projectiles - Conventional, Truncated and Tipped Truncated Ogival Types," Frankford Arsenal Report R-1166, Dec. 1953.

[3]H. E. Fatzinger and J. R. Kymer, "Penetration Performance vs Projectile Nose Hardness," Frankford Arsenal Report R-1177, Dec. 1953.

tips were attached to the shot bodies with Chrysler Cycleweld C-14 plastic cement. A photograph and drawing of the assembly are included in Figures 1 and 2. Three lots of shot had rotating bands made of the same plastic cement, one lot of shot had copper rotating bands. Plastic rotating bands were used to eliminate the requirement of a band seat (necessary for the conventional copper band) in which cracks often originate during quenching.

The lot numbers, steels, body and tip hardnesses, weights, and rotating band types are included in Tables I and II.

Table I. Shot Body Hardness Tests

Shot Body					*Tip (Mn Mo)*		
Hardness (Rc)*	*Lot Number*	*Steel*	*Weight (gr)*	*Rotating Band*	*Hardness (Rc)*	*Weight (gr)*	*Total Weight*
66	2082F-T	Hampden	1700	Plastic	59 to 61	200	1900
63	2169F-T	Mn Mo**	1665	Copper	59 to 61	200	1865
55	2169F-T	Mn Mo	1665	Copper	59 to 61	200	1865

*Hardness in ogival and bourrelet regions
**Mn Mo - Manganese Molybdenum Steel (Fed Spec 57-107-33)

Table II. Tip Hardness Tests

Tip			*Shot Body (Mn Mo)*				
Hardness (Rc & Bhn)*	*Material*	*Weight (gr)*	*Lot Number*	*Hardness (Rc)*	*Weight (gr)*	*Rotating Band*	*Total Weight*
59 to 61 Rc (600 to 628 Bhn)	Mn Mo	200	2067F-T	63	1600	Plastic	1800
43 to 45 Rc (408 to 430 Bhn)	Mn Mo	200	2067F-T	63	1600	Plastic	1800
120 Bhn	24S-T4	70	2083F-T	62	1685	Plastic	1755

*24S-T4 - Aluminum alloy

All shot bodies and steel tips were machined from 13/16 inch diameter bar stock supplied by Carpenter Steel Company. The steel tips and shot bodies of Lots: 2169F-T, 2083F-T, and 2067F-T were machined from manganese molybdenum (Mn Mo, Fed Spec 57-107-33) steel. Shot of Lot 2082F-T were machined from Hampden (high carbon, high chromium) steel so that high hardness could be obtained. The softest tips were made from one inch diameter 24S-T4 aluminum bar stock.

Composition. Compositions are listed in Table III.

Table III. Per Cent Composition

Steel	*C*	*Mn*	*Mo*	*P*	*S*	*Si*	*Ni*	*Cr*	*V*
Fed Spec 57-107-33	0.74	0.90	1.04	0.02	0.04	0.33	0.05	0.15	0.02
Hampden	2.06	0.33	-	-	-	0.29	0.51	12.41	-

Nominal Composition of 24S-T4 Aluminum Alloy

Alloying elements	*Cu*	*Si*	*Fe*	*Mn*	*Mg*	*Al*
	4.5	0.5	0.5	0.6	1.5	remainder

Heat Treatment. The manganese molybdenum (Mn Mo) steel shot bodies were austenitized in salt at 1550° F, quenched in brine, over-all tempered at 250° F and base tempered by induction. In addition, the softest shot bodies (55 Rc) were tempered at 575° F. The Hampden steel shot bodies were austenitized at 1850° F, quenched in oil, over-all tempered at 200° F and base tempered by induction. Steel tips were austenitized at 1650° F, marquenched at 375° F, cooled to room temperature, and over-all tempered at 250° F. In addition, the 43 to 45 Rockwell C tips were tempered at 950° F. These treatments produced a tempered martensitic microstructure. Hardness patterns for the various lots of shot are included in Figures 3, 4, and 5.

Plate

All firings were conducted against rolled homogeneous (class B) armor. The plate thickness, obliquity, and hardness for the body hardness and tip hardness tests are listed in Tables IV and V.

Table IV. Armor Plates Used in FAPT Body Hardness Tests

Test Condition			*Body Hardness (Rc)*					
Thickness		*Obliquity*	*66*		*63*		*55*	
In.	*Caliber*	*Degree*	*No.*	*Bhn*	*No.*	*Bhn*	*No.*	*Bhn*
1 1/8	1.43	45	21	311 to 321	17	321 to 331	21	311 to 321
1	1.27	55	31	293 to 302	20	302	-	-
1	1.27	45	31	293 to 302	20	302	20	302
7/8	1.11	60	56	293 to 306	51	302	-	-
7/8	1.11	55	56	293 to 306	51	302	51	302
7/8	1.11	30	56	293 to 306	51	302	51	302
3/4	0.95	60	46	306 to 311	39	293 to 302	39	293 to 302

Table V. Armor Plates Used in FAPT Tip Hardness Tests

Test Condition			Steel				24S-T4 Aluminum	
Thickness		Obliquity	59 to 61 Rc (600 to 628 Bhn)		43 to 45 Rc (408 to 430 Bhn)		(120 Bhn)	
In.	Caliber	Degree	No.	Bhn	No.	Bhn	No.	Bhn
1	1.27	30	31	293 to 302	31	293 to 302	31	293 to 302
7/8	1.11	55	53	302 to 311	53	302 to 311	-	
3/4	0.95	60	-		-		46	306 to 311
5/8	0.79	60	24	311 to 321	24	311 to 321	25	311 to 321

METHODS

Firing

A 20 mm Mann type barrel chambered for the T20 case (.60/20 mm) was used for all firings. For velocities in excess of 3000 fps, a special chamber extension was screwed onto the above barrel to accommodate a two-piece, double length case. The distance from the muzzle to the plate was 215 feet. Velocities were measured on counter chronographs actuated by three pairs of solenoids, the base line centers of which were 32, 87, and 132 feet from the plate. Three pairs of solenoids were used in order to obtain measurements of the projectile retardation to correct the measured velocities to actual striking velocities.

Evaluation

Protection ballistic limits were used as the criterion for comparing the penetration performance of the various shot groups as a function of shot body and tip hardness. For some test conditions, ballistic limits could not be determined because of gun velocity limitations. The majority of ballistic limits were obtained by averaging the velocities of the highest partial and lowest complete penetrations for each group. For firings where a zone of mixed partial and complete penetrations occurred, the ballistic limit was obtained by averaging the velocities in the zone, including those of the highest partial and lowest complete penetrations.

Figures 6 to 16, inclusive, represent plots of rounds fired for the various shot groups as a function of striking velocity. Protection ballistic limits are indicated between the partial and complete penetration velocities along with the intact or shattered condition of the shot.

All shot were recovered in plywood and were examined for the extent of deformation and failure. A description of the recovered shot for each round is included in the Appendix.

RESULTS AND DISCUSSION

Body Hardness Tests

20 mm Results. Table VI summarizes the protection ballistic limits obtained with tipped truncated shot of three body hardnesses for each target condition investigated.

Table VI. Summary - Protection Ballistic Limits (fps) vs FAPT Shot Body Hardness

Test Condition			*Body Hardness**		
Thickness		*Obliquity*	*66 Rc*	*63 Rc*	*55 Rc*
In.	*Caliber*	*Degree*	*(Hampden)*	*(Mn Mo)*	*(Mn Mo)*
1 1/8	1.43	45	> 3440	> 3550	> 3635
1	1.27	55	> 3440	> 3625	-
1	1.27	45	2680	2825	> 3260
7/8	1.11	60	> 3500	> 3570	-
7/8	1.11	55	3145	3055	3390
7/8	1.11	30	2245	2170	2590**
3/4	0.95	60	2980	3050	3250

*Hardness in ogival and bourrelet regions
**Approximated velocity

Unfortunately, comparisons could not be made for the more difficult test conditions where ballistic limits were not obtained. No significant difference in ballistic limits and penetration performance was observed between FAPT shot bodies of 66 and 63 Rockwell C hardnesses. Against one-inch plate at 45° obliquity and 3/4-inch plate at 60° obliquity, the shot bodies of conventional hardness (63 Rc) were slightly inferior to the hardest bodies (66 Rc). Against 7/8-inch plate at 55° and 30° obliquities the shot bodies of conventional hardness were slightly superior to the hardest shot. However, the softest shot bodies (55 Rc) were inferior to the harder ones under all test conditions for which comparisons could be made. The softest shot were not fired against one-inch plate at 55° obliquity and 7/8-inch plate at 60° obliquity because these targets could not be defeated with the hard shot bodies.

During penetration it is important that the biting edge of the nose flat of the FAPT shot body remain intact as long as possible so that it can dig into the plate and eject a punching. The biting edge of truncated hard shot resists shearing for a longer time than that of soft shot. Soft shot bodies also deform and shatter to a greater extent during penetration, which makes them inferior to the harder shot bodies. However, if shot bodies are made too hard, they become too brittle. As a result, they tend to fracture on impact and may be inferior to soft shot. This probably accounts for the fact that the hardest shot (65 Rc), which were of a different steel composition, were not superior but actually were slightly inferior in two firings to the conventional ones (63 Rc). The effect of composition upon penetration performance with this projectile type, remains to be investigated.

76 mm Results. Limited firings were conducted at Aberdeen Proving Ground with tipped truncated hemispherical ogival 76 mm AP T166E2 shot of three different body hardnesses. Shot bodies made of NE 98V65 steel of conventional hardness (60 to 61 Rc) were compared with softer shot bodies (57 to 58 Rc) of the same steel and with harder shot bodies (65 to 66 Rc) made of high carbon, high chromium steel. Firings were conducted against two inch thick rolled homogeneous plate at 60° obliquity and against four inch thick homogeneous plate at 30° obliquity. Results of these firings are summarized in Table VII.

Table VII. Summary - Protection Ballistic Limits (fps)

vs 76 mm AP T166E2 (Tipped) Shot Body Hardness

Test Condition			*Body Hardness*		
Thickness		*Obliquity*	*65 to 66 Rc*	*60 to 61 Rc*	*57 to 58 Rc*
In.	*Caliber*	*Degree*	*(Hi C, Hi Cr)*	*(98V65)*	*(98V65)*
2	0.67	60	2115	1995	2035
4	1.33	30	2895	2690	2775

Hi C, Hi Cr = High carbon, high chromium steel.

In these firings, shot bodies of conventional hardness (60 to 61 Rc) were superior to the harder ones (65 to 66 Rc) and only slightly superior to the softer shot bodies (57 to 58 Rc) against both targets. The hardest shot were more inferior than the softest ones; probably, because of higher brittleness. At the 76 mm scale the softest shot were only slightly inferior to those of conventional hardness whereas at the 20 mm scale the softest shot were greatly inferior. The effect of composition upon penetration performance was not investigated at either scale. A report on Project TA1-1301 describing these results in greater detail, along with other results of T166 shot firings, will be prepared in the near future.

Tip Hardness Tests

Results of these firings are summarized in Table VIII.

Table VIII. Summary - Protection Ballistic Limits (fps) vs FAPT Tip Hardness

Test Condition			*Tip Hardness*		
Thickness			*Steel (Mn Mo)*		*24S-T4*
In.	*Caliber*	*Obliquity Degree*	*59 to 61 Rc 600 to 628 Bhn*	*43 to 45 Rc 408 to 430 Bhn*	*Aluminum 120 Bhn*
1	1.27	30	2600*	2600	3200*
7/8	1.11	55	2990	≧ 2935**	-
3/4	0.95	60	3000*	-	3195
5/8	0.79	60	2500	2550	2590

*Approximated velocity
**Partial penetrations were obtained above this velocity up to 3255 fps

No significant difference was observed between the hard and soft steel tipped shot although partial penetrations resulted with the soft tipped shot at velocities above the 2935 fps ballistic limit of 7/8-inch plate at 55° obliquity. The aluminum, or softest tips, performed almost as well as the steel tips against 5/8-inch plate at 60°, but were more inferior against 3/4-inch plate at 60° obliquity. Against the one-inch plate at 30° obliquity the aluminum tips were much inferior to the steel tips. The ballistic limit of the 3/4-inch plate at 60° with steel tips was approximated from previous firings with a similar lot of FAPT shot.

CONCLUSIONS

1. At the 20 mm scale tipped truncated (FAPT) shot having bodies of conventional hardness (63 Rc) are greatly superior to those having bodies of lower hardness (55 Rc).

2. There is no consistent significant difference in penetration performance between tipped shot bodies of 63 and 66 Rockwell C hardnesses.

3. For the two target conditions investigated at the 76 mm scale, FAPT shot bodies of conventional hardness (60 to 61 Rc) are only slightly superior to those of lower hardness (57 to 58 Rc) but are superior by as much as 200 fps to those of higher hardness (65 to 66 Rc).

4. At both scales, therefore, these tests indicate that the hardness of FAPT shot bodies should be neither higher nor lower than conventional.

5. At the 20 mm scale there is no significant difference in ballistic performance between FAPT shot having hard steel tips (59 to 61 Rc) and those having softer steel tips (43 to 45 Rc). Aluminum tipped shot are almost as efficient as steel tips against 5/8 inch (0.79 caliber) thick plate at 60° obliquity but are greatly inferior to the steel tipped shot against one-inch (1.27 caliber) plate at 30° obliquity.

APPENDIX

Abbreviations Describing Penetration Results

PP	- Partial penetration
CP(A)	- Complete penetration - Army criterion*
CP(P)	- Complete penetration - Protection criterion*
CP(NI)	- Complete penetration - Navy criterion, shot intact*
CP(NF)	- Complete penetration - Navy criterion, shot fractured*
CP(NS)	- Complete penetration - Navy criterion, shot shattered*
NB	- No bulge
VSB	- Very small bulge
SB	- Small bulge
MB	- Medium bulge
LB	- Large bulge
VLB	- Very large bulge
Ck	- Cracks
NCk	- No cracks
PO	- Plug out
PH	- Plug hanging
PS	- Plug started
BP	- Back petals
BPO	- Back petals off
BPS	- Back petals started
BS	- Back spall
BSS	- Back spall started
BSH	- Back spall hanging
FP	- Front petals
FPO	- Front petals off
FS	- Front spall
NI**	- Nose intact
BI***	- Base intact
SI	- Shot intact
Sh	- Shatter
Fr	- Fracture
LS	- Local shear
PBL	- Protection ballistic limit
Scoop	- Shot scoop, extent in inches
a	- Bracketing velocities used to calculate protection ballistic limit
b	- Velocities averaged in zone of mixed results to obtain protection ballistic limit

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* Defined according to Ordnance Department Bulletin No. 24-44

** Fractions following NI indicate approximate ratio of nose fragment to total shot body

*** Fractions following BI indicate approximate ratio of base fragment to total shot body

FIRING RECORD

I. FAPT Body Hardness Tests

A. Firing Against 1 1/8-Inch Homogeneous Armor at 45° Obliquity

Striking Velocity	*Penetration Results* *Plate*	*Shot*	*Scoop*
	66 Rockwell C - Lot 2082 F-T vs Plate No. 21		
3442	PP-SB	Sh	(2.2 x 1.5)
3420	PP-MB	Sh	(1.8 x 1.5)
	PBL > 3440		
	63 Rockwell C - Lot 2169 F-T vs Plate No. 17		
3550	PP-LB-NCk	BI 1/3-Sh-Fr-LS	(1.7 x 1.7)
3505	PP-LB-NCk	BI 1/3-Sh-Fr-LS	(1.9 x 1.7)
	PBL > 3550		
	55 Rockwell C - Lot 2169 F-T vs Plate No. 21		
3635	PP-LB-NCk	Sh-Fr-LS	(2.0 x 1.8)
	PBL > 3625		

B. Firing Against One-Inch Homogeneous Armor at 55° Obliquity

Striking Velocity	*Plate*	*Shot*	*Scoop*
	66 Rockwell C - Lot 2082 F-T vs Plate No. 31		
3440	PP-LB-NCk	Sh	(2.2 x 1.4)
3432	PP-LB-NCk	Sh	(2.1 x 1.4)
	PBL > 3440		
	63 Rockwell C - Lot 2169 F-T vs Plate No. 20		
3625	PP-LB-Ck	Sh-Fr-LS	(2.3 x 1.4)
3520	PP-LB-NCk	BI 1/3 - Sh-Fr-LS	(2.1 x 1.4)
	PBL > 3625		

I. FAPT Body Hardness Tests (Cont'd)

C. Firing Against One-Inch Homogeneous Armor at 45° Obliquity

Striking Velocity		Penetration Results: Plate	Shot	Scoop
		66 Rockwell C - Lot 2082 F-T vs Plate No. 31		
2790		CP(A&P)-PO	Sh	(2.2 x 1.2)
2689 a		CP(A&P)-PH	Sh-Fr	(1.6 x 1.1)
2675 a		PP-PS	SI-LS at Nose	(1.9 x 1.2)
2628		PP-PS	Fr-LS	(2.0 x 1.1)
		PBL = 2680		
		63 Rockwell C - Lot 2169 F-T vs Plate Nos. 20, 31		
2945	(31)	CP(NS)-PO	Sh-Fr-LS	(2.1 x 1.2)
2926	(20)	CP(A&P)-BP	BI 1/3-Sh-Fr-LS	(1.8 x 1.3)
2835 a	(20)	PP-PS	BI 3/4-Fr-LS	(2.0 x 1.2)
2820 a	(31)	CP(A&P)-PO	BI 2/5-Sh-Fr-LS	(2.1 x 1.3)
2718	(31)	PP-PS	BI 2/5-Sh-Fr-LS	(2.1 x 1.2)
2712	(31)	PP-PS	BI 1/4-Sh-Fr-LS	(1.9 x 1.2)
		PBL = 2825		
		55 Rockwell C - Lot 2169 F-T vs Plate No. 20		
3257		PP-LB-Ck	BI 2/5-Sh-Fr-LS	(1.9 x 1.6)
3065		PP-MB-NCk	Sh-Fr-LS	(1.8 x 1.4)
2875		PP-MB-NCk	BI 2/3-Sh-Fr-LS	(2.0 x 1.3)
		PBL = 3260		

I. FAPT Body Hardness Tests (Cont'd)

D. Firing Against 7/8-Inch Homogeneous Armor at 60° Obliquity

Striking Velocity	*Penetration Results*		
	Plate	*Shot*	*Scoop*
	66 Rockwell C - Lot 2082 F-T vs Plate No. 56		
3498	PP-LB-Ck	Sh-Fr-LS	(2.2 x 1.1)
3345	PP-LB-Ck	Sh-Fr-LS	(2.1 x 1.1)
3342	CP(A&P)-PO	Sh-Fr-LS	(2.2 x 1.5)
3340	PP-LB-Ck	Sh-Fr-LS	(2.1 x 1.5)
3253	PP-LB-NCk	Sh-Fr-LS	(2.1 x 1.4)
	PBL > 3500		
	63 Rockwell C - Lot 2169 F-T vs Plate Nos. 51, 56		
3589 (56)	PP-LB-NCk	BI 1/4-Sh-Fr-LS	(2.6 x 1.4)
3570 (51)	CP(A&P)-PO	Sh-Fr-LS	(2.2 x 1.5)
3568 (56)	PP-LB-Ck	Sh-Fr-LS	(2.2 x 1.3)
3485 (51)	PP-LB-Ck	Sh-Fr-LS	(2.0 x 1.3)
	PBL > 3570		

I. FAPT Body Hardness Tests (Cont'd)

E. Firing Against 7/8-Inch Homogeneous Armor at 55° Obliquity

Striking Velocity	*Penetration Results*		
	Plate	*Shot*	*Scoop*
	66 Rockwell C - Lot 2082 F-T vs Plate No. 56		
3177	CP(A&P)-PO	Sh-Fr-LS	(2.2 x 1.2)
3158 a	CP(A&P)-PO	Sh-Fr-LS	(2.0 x 1.2)
3131 a	PP-LB-Ck	Sh-Fr-LS	(2.3 x 1.1)
3065	PP-LB-NCk	Sh-Fr-LS	(2.3 x 1.2)
	PBL = 3145		
	63 Rockwell C - Lot 2169 F-T vs Plate Nos. 51, 56		
3164 (56)	CP(A&P)-PO	Sh-Fr-LS	(1.9 x 1.4)
3112 (56)	CP(A&P)-PO	Sh-Fr-LS	(2.0 x 1.3)
3080 a (51)	CP(A&P)-PO	Sh-Fr-LS	(2.1 x 1.2)
3030 a (51)	PP-PS	BI 1/4-Sh-Fr-LS	(2.1 x 1.2)
	PBL = 3055		
	55 Rockwell C - Lot 2169 F-T vs Plate No. 51		
3555	CP(NS)-PO	BI 2/5-Sh-Fr-LS	(2.1 x 1.5)
3430 a	CP(NS)-PO	BI 1/3-Sh-Fr-LS	(2.2 x 1.4)
3350 a	PP-LB-PS	Sh-Fr-LS	(2.1 x 1.4)
3275	PP-LB-Ck	BI 3/5-Sh-Fr-LS	(2.5 x 1.2)
3125	PP-LB-NCk	BI 1/2-Sh-Fr-LS	(2.2 x 1.2)
	PBL = 3390		

I. FAPT Body Hardness Tests, (Cont'd)

F. Firing Against 7/8-Inch Homogeneous Armor at 30° Obliquity

Striking Velocity	Penetration Results: Plate	Shot	Scoop
	66 Rockwell C - Lot 2082 F-T vs Plate No. 56		
2270 a	CP(A&P)-PO	NI 1/4-BI 3/4-Fr	(2.0 x 1.2)
2220 a	CP(A)-PH	BI 3/4-Fr	(2.0 x 1.0)
2155	PP-LB-Ck	BI 7/8-Fr-LS	(2.0 x 1.1)
2120	PP-LB-NCk	BI 7/8-Fr-LS	(2.0 x 1.1)
	PBL = 2245		
	63 Rockwell C - Lot 2169 F-T vs Plate No. 51		
2312	CP(NI)-PO	SI-LS at Nose	(1.7 x 1.1)
2197 a	CP(A&P)-PO	NI 1/2-BI 1/2-Fr	(1.6 x 1.3)
2145 a	PP-LB-NCk	SI-LS at Nose	(1.7 x 1.3)
2073	PP-SB-NCk	BI 7/8-Fr	(1.9 x 1.1)
	PBL = 2170		
	55 Rockwell C - Lot 2169 F-T vs Plate Nos. 51, 56		
2668 (56)	CP(NS)-PO	BI 3/4-Sh-Fr-LS	(1.7 x 1.5)
2659 a (56)	CP(A&P)-PO	BI 1/2-Sh-Fr-LS	(1.6 x 1.3)
2518 a (56)	CP(A)-LB-Ck	BI 1/2-Sh-Fr-LS	(1.8 x 1.3)
2426 (56)	PP-MB-NCk	BI 1/2-Sh-Fr-LS	(1.8 x 1.3)
2321 (51)	CP(A&P)-PO	BI 7/8-LS at Nose	(1.6 x 1.3)
2284 (51)	PP-LB-Ck	BI 3/5-Sh-Fr-LS	(1.6 x 1.2)
	PBL = Approx 2590		

I. FAPT Body Hardness Tests (Cont'd)

G. Firing Against 3/4-Inch Homogeneous Armor at 60° Obliquity

Striking Velocity	Penetration Results: Plate	Shot	Scoop
	66 Rockwell C - Lot 2082 F-T vs Plate No. 46		
3216	CP(A&P)-PO	Sh-Fr-LS	(2.1 x 1.2)
3035 b	CP(A&P)-PO	Sh-Fr-LS	(1.9 x 1.2)
2995 b	PP-MB-NCk	Sh-Fr-LS	(3.1 x 1.2)
2965 b	CP(A&P)-PO	Sh-Fr-LS	(2.1 x 1.2)
2913 b	PP-MB-NCk	Sh-Fr-LS	(2.7 x 1.1)
	PBL = 2980		
	63 Rockwell C - Lot 2169 F-T vs Plate Nos. 39, 46		
3104 (46)	CP(A&P)-PO	Sh-Fr-LS	(2.4 x 1.4)
3090 (46)	CP(A&P)-PO	BI 1/4-Sh-Fr-LS	(2.2 x 1.1)
3086 a (39)	CP(A&P)-PO	Sh-Fr-LS	(2.1 x 1.2)
3018 a (46)	PP-LB-Ck	BI 1/4-Sh-Fr-LS	(2.4 x 1.2)
3015 (39)	PP-LB-Ck	BI 3/4-Fr	(2.9 x 1.2)
	PBL = 3050		
	55 Rockwell C - Lot 2169 F-T vs Plate No. 39		
3328	CP(NS)-PO	BI 3/5-Sh-LS	(2.6 x 1.3)
3283 a	CP(A&P)-PO	BI 1/3-Sh-Fr-LS	(2.6 x 1.3)
3211 a	PP-LB-NCk	BI 1/2-Sh-Fr-LS	(2.8 x 1.3)
3027	PP-LB-NCk	BI 1/2-Sh-Fr-LS	(2.6 x 1.2)
	PBL = 3250		

II. FAPT Tip Hardness Tests

A. Firing Against One-Inch Homogeneous Armor at 30° Obliquity

Striking Velocity	*Penetration Results*		
	Plate	*Shot*	*Scoop*
	59-61 Rockwell C Steel Tip - Lot 2067 F-T vs Plate No. 31		
2889	CP(NS)-PO	BI 3/5-Sh-Fr-LS	(1.7 x 1.6)
2823	CP(NS)-PO	Sh-Fr-LS	(1.7 x 1.5)
2766	CP(NS)-PO	BI 2/3-Sh-Fr-LS	(1.6 x 1.5)
2740 b	PP-LB-Ck	Sh-Fr-LS	(1.7 x 1.5)
2680 b	CP(A&P)-PO	Sh-Fr-LS	(1.5 x 1.3)
2675 b	CP(NS)-PO	BI 3/4-Sh-Fr-LS	(1.6 x 1.3)
2620 b	PP-LB-Ck	Sh-Fr-LS	(1.5 x 1.4)
2595 b	CP(NS)-PO	Sh-Fr-LS	(1.7 x 1.4)
2495 b	PP-LB-Ck	BI 2/3-Sh-Fr-LS	(1.9 x 1.3)
2485 b	CP(A&P)-PO	BI 2/3-Sh-Fr-LS	(1.9 x 1.0)
2425	PP-MB-NCk	Sh-Fr-LS	(2.0 x 1.2)
2300	PP-MB-NCk	BI 3/4-Fr-LS	(2.0 x 1.3)
	PBL = Approx 2600		
	43-45 Rockwell C Steel Tip - Lot 2067 F-T vs Plate No. 31		
2890	CP(NS)-PO	Sh-Fr-LS	(1.8 x 1.3)
2640	CP(NS)-PO	BI 1/2-Sh-Fr-LS	(1.4 x 1.2)
2625	CP(A&P)-PO	BI 3/5-Sh-Fr-LS	(1.5 x 1.1)
2625 a	CP(A&P)-PO	BI 2/3-Sh-Fr-LS	(1.6 x 1.3)
2570 a	PP-LB-Ck	BI 1/3-Sh-Fr-LS	(1.4 x 1.1)
2515	PP-LB-Ck	BI 2/3-Sh-Fr-LS	(1.5 x 1.2)
	PBL = 2600		
	120 Brinell Aluminum Tip - Lot 2083 F-T vs Plate No. 31		
3237 a	CP(A&P)-PO	Sh-Fr-LS	(1.7 x 1.6)
3155 a	PP-LB-Ck	Sh-Fr-LS	(1.7 x 1.5)
3065	PP-MB-NCk	Sh-Fr-LS	(1.6 x 1.5)
2957	PP-MB-NCk	Sh-Fr-LS	(1.7 x 1.4)
2603	PP-SB-NCk	Sh-Fr-LS	(1.5 x 1.4)
	PBL = Approx 3200		

II. FAPT Tip Hardness Tests (Cont'd)

B. Firing Against 7/8-Inch Homogeneous Armor at 55° Obliquity

Striking Velocity	Penetration Results: Plate	Shot	Scoop
	59-61 Rockwell C Steel Tip - Lot 2067 F-T vs Plate No. 53		
3247	CP(NS)-PO	Sh-Fr-LS	(2.2 x 1.2)
3128	CP(A&P)-PO	BI 1/4-Sh-Fr-LS	(2.0 x 1.1)
3128	CP(A&P)-PO	Sh-Fr-LS	(2.2 x 1.0)
3080 b	PP-MB-NCk	Sh-Fr-LS	(2.1 x 1.3)
2987 b	CP(A&P)-PO	Sh-Fr-LS	(2.1 x 1.1)
2985 b	PP-LB-NCk	SI	(2.7 x 1.3)
2915 b	CP(A&P)-PO	BI 3/5-Fr-LS	(2.2 x 1.0)
2842	PP-LB-NCk	SI 9/10-Fr	(2.5 x 1.2)
2740	PP-MB-NCk	SI 4/5-Fr	(2.5 x 1.2)
	PBL = 2990		
	43-45 Rockwell C Steel Tip - Lot 2067 F-T vs Plate No. 53		
3255	PP-LB-NCk	Sh-Fr-LS	(2.1 x 1.3)
3075	PP-LB-PS	BI 1/3-Sh-Fr-LS	(2.0 x 1.1)
3048	PP-LB-PS	Sh-Fr-LS	(1.9 x 1.2)
2962	PP-MB-NCk	BI 3/4-Fr	(2.4 x 1.0)
2945	CP(A&P)-PO	Sh-Fr-LS	(2.1 x 1.2)
2935 a	CP(A&P)-PO	BI 1/3-Sh-Fr-LS	(2.0 x 1.2)
2935 a	PP-MB-NCk	BI 1/2-Sh-Fr-LS	(2.3 x 1.2)
2875	PP-LB-Ck	Sh-Fr-LS	(2.0 x 1.0)
2805	PP-MB-NCk	SI	(2.5 x 1.2)
	PBL $\geqq$ 2935		

II. FAPT Tip Hardness Tests (Cont'd)

C. Firing Against 3/4-Inch Homogeneous Armor at 60° Obliquity

Striking Velocity	Penetration Results: Plate	Shot	Scoop
	120 Brinell Aluminum Tip - Lot 2083 F-T vs Plate No. 46		
3280	CP(A&P)-PO	Sh-Fr-LS	(2.0 x 1.4)
3195 a	CP(A&P)-PO	Sh-Fr-LS	(1.9 x 1.4)
3195 a	CP(A)-PH	Sh-Fr-LS	(2.5 x 1.1)
3150	PP-MB-NCk	Sh-Fr-LS	(2.0 x 1.5)

PBL = 3195

D. Firing Against 5/8-Inch Homogeneous Armor at 60° Obliquity

Striking Velocity	Plate	Shot	Scoop
	59-61 Rockwell C Steel Tip - Lot 2067 F-T vs Plate No. 24		
2625	CP(A&P)-PO	SI-Ck'd	(2.5 x 1.0)
2565 b	CP(A&P)-PO	BI 2/3-Sh-Fr-LS	(2.2 x 1.0)
2553 b	CP(A&P)-PO	SI-Ck'd	(2.1 x 1.0)
2545 b	PP-LB-Ck	SI-Ck'd	(2.8 x 1.0)
2475 b	PP-PS	SI-Ck'd	(2.5 x 1.0)
2455 b	PP-LB-Ck	SI-Ck'd	(2.6 x 1.0)
2425 b	CP(A&P)-PO	Sh-Fr-LS	(2.1 x 1.0)
2400	PP-LB-NCk	SI	(2.5 x 1.0)
2295	PP-MB-NCk	SI	(2.6 x 1.0)
2225	PP-MB-NCk	SI	(2.6 x 1.0)

PBL = 2500

II. FAPT Tip Hardness Tests (Cont'd)

D. Firing Against 5/8-Inch Homogeneous Armor at 60° Obliquity (Cont'd)

Striking Velocity	Penetration Results Plate	Shot	Scoop
	43-45 Rockwell C Steel Tip - Lot 2067 F-T vs Plate No. 24		
2670	CP(A&P)-PO	SI-Ck'd	(2.7 x 1.0)
2640	CP(A&P)-PO	SI-Ck'd	(2.5 x 1.1)
2590 b	CP(A&P)-PO	SI	(2.7 x 1.0)
2590 b	CP(A&P)-PO	SI	(2.6 x 1.1)
2585 b	CP(A)-PS	SI	(2.4 x 1.0)
2525 b	PP-LB-Ck	SI	(2.5 x 1.0)
2525 b	PP-LB-Ck	SI	(2.7 x 1.0)
2490 b	CP(A&P)-PO	SI	(2.7 x 1.1)
2420	CP(A)-PS	SI	(2.5 x 1.0)
2370	PP-LB-NCk	SI	(2.8 x 1.0)
	PBL = 2550		
	120 Brinell Aluminum Tip - Lot 2083 F-T vs Plate No. 25		
2743	CP(A&P)-PO	SI	(2.5 x 1.0)
2626 a	CP(A&P)-PO	SI	(2.8 x 1.0)
2553 a	PP-LB-Ck	SI	(2.8 x 1.1)
2553 a	PP-LB-Ck	SI	(2.8 x 1.1)
	PBL = 2590		

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R-1189

Aluminum Tip
Plastic Band

Steel Tips

Copper Band

Plastic Band

Figure 1. Tipped truncated ogival 20 mm AP T33 shot showing tips and rotating bands used

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R-1189

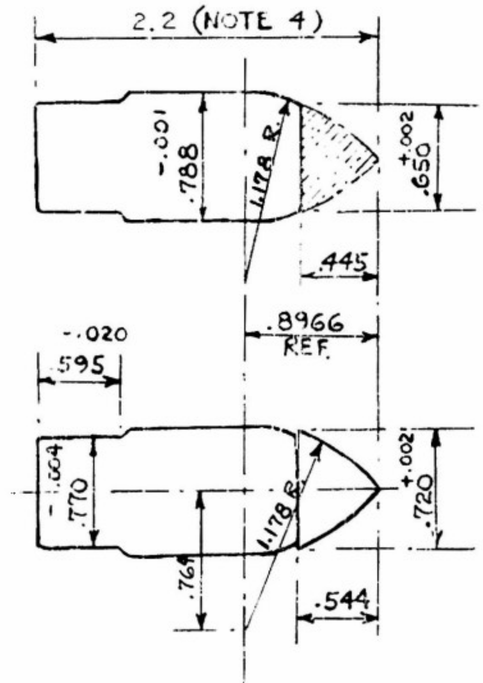
NOTES:

1. Tips on FAPT shot are attached to bodies with plastic Cycleweld cement.

2. Shot have plastic rotating bands.

3. Body (bourrelet) dia - after centerless grinding.

4. Length of conventional 20 mm AP T33 varied to meet finished wt requirement of 1800 grains.



Truncated Conventional
(FAP)

Tipped Truncated
(FAPT)

Figure 2. 20 mm AP T33 Type Shot

Neg. #24754-3
R-1189

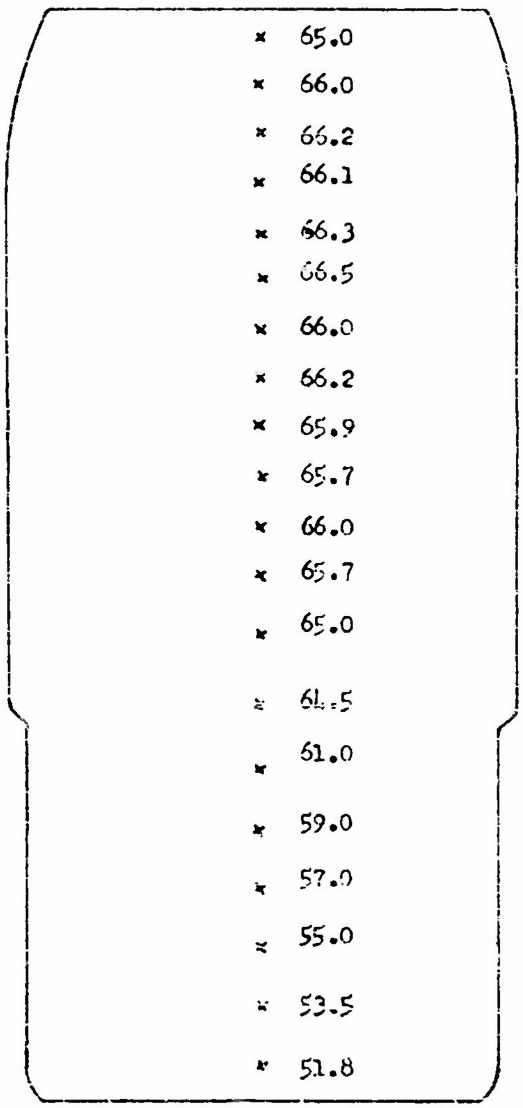


Figure 3. Rockwell C hardness pattern for Hampden steel FAPT shot bodies -- Lot 2082F-T

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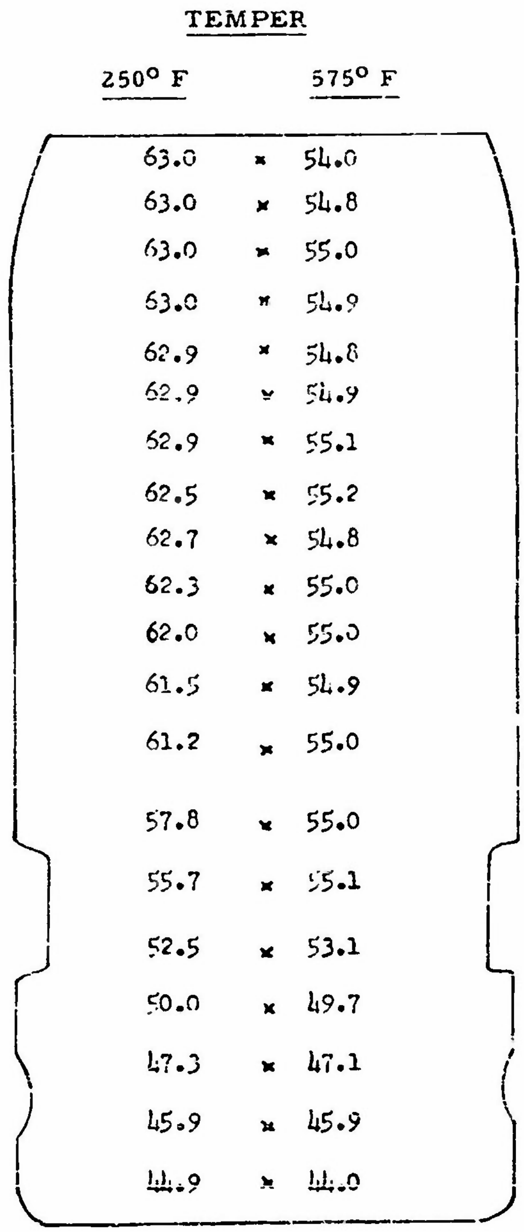

Figure 4. Rockwell C hardness patterns for manganese molybdenum steel FAPT shot bodies - Lot 2169F-T

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R-1189

LOT

2067F-T		2083F-T
63.2	×	62.2
63.0	×	62.2
63.5	×	62.8
63.0	×	62.8
63.5	×	62.0
63.4	×	62.2
63.1	×	62.0
63.1	×	62.0
63.1	×	62.0
63.0	×	62.2
62.5	×	60.2
62.3	×	61.2
60.8	×	61.5
57.8	×	60.8
54.8	×	58.0
52.3	×	55.0
49.5	×	53.2
48.2	×	51.5
46.9	×	50.0
45.3	×	42.2

Figure 5. Rockwell C hardness patterns for manganese molybdenum steel FAPT shot bodies - Lots 2067F-T and 2083F-T

Neg. #24754-6
R-1189

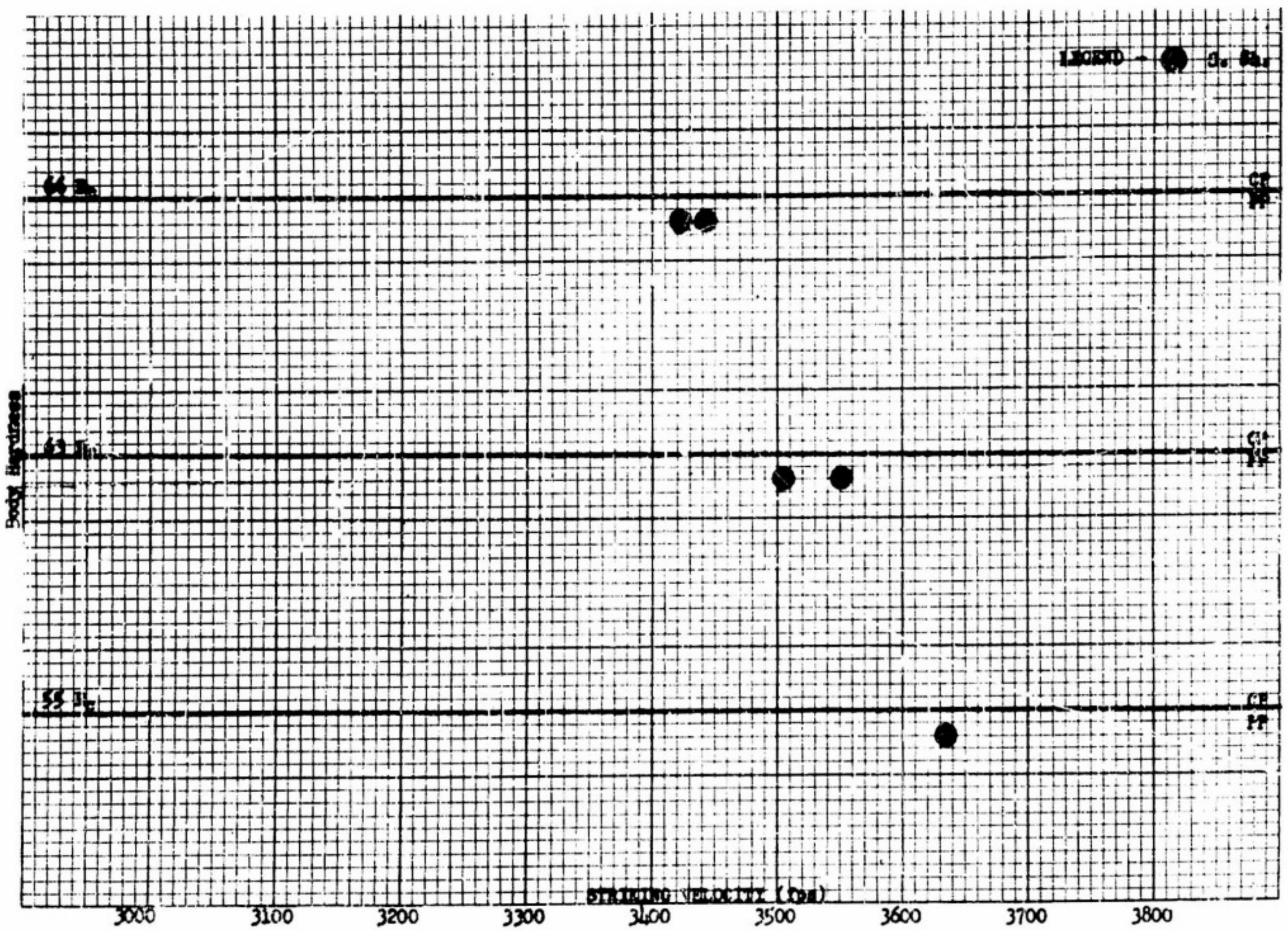

Figure 6. FAPT shot body hardness firings vs 1 1/8-inch homogeneous plate at 45° obliquity

Neg. #24754-7
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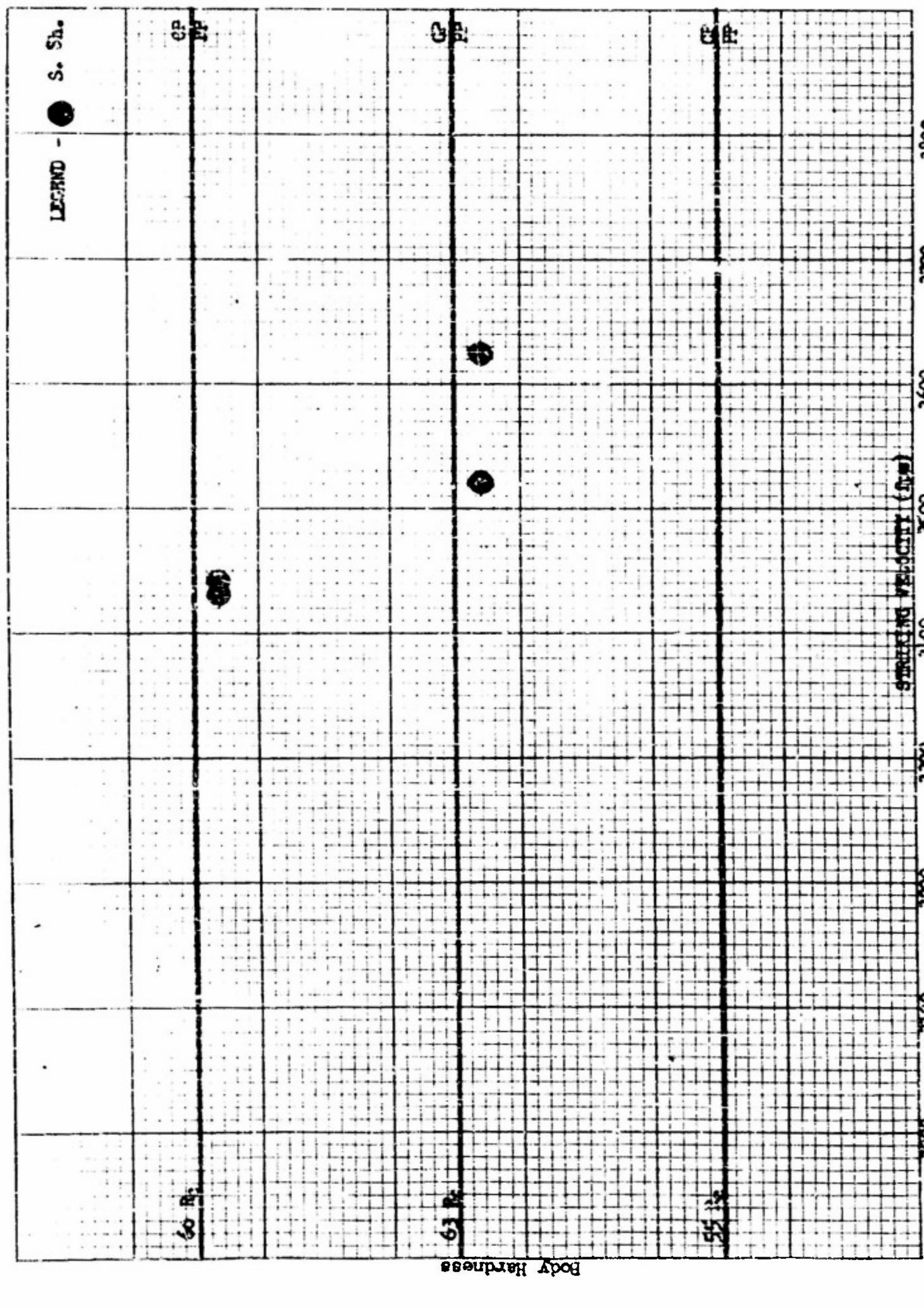

Figure 7. FAPT shot body hardness firings vs 1-inch homogeneous plate at 55° obliquity

Neg. #24754-8
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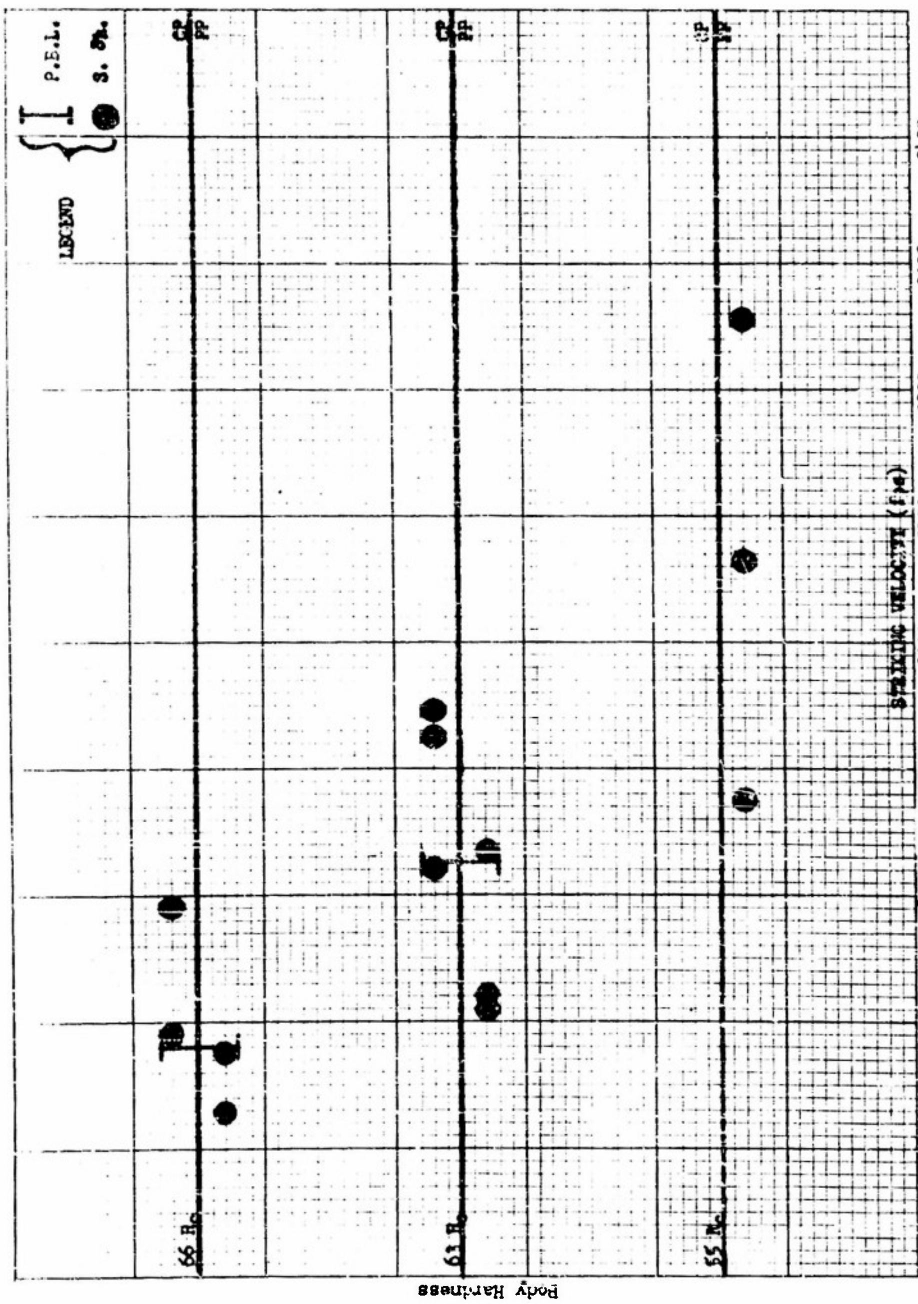

Figure 8. FAPT shot body hardness firings vs 1-inch homogeneous plate at 45° obliquity

Neg. #24754-?
R-1189

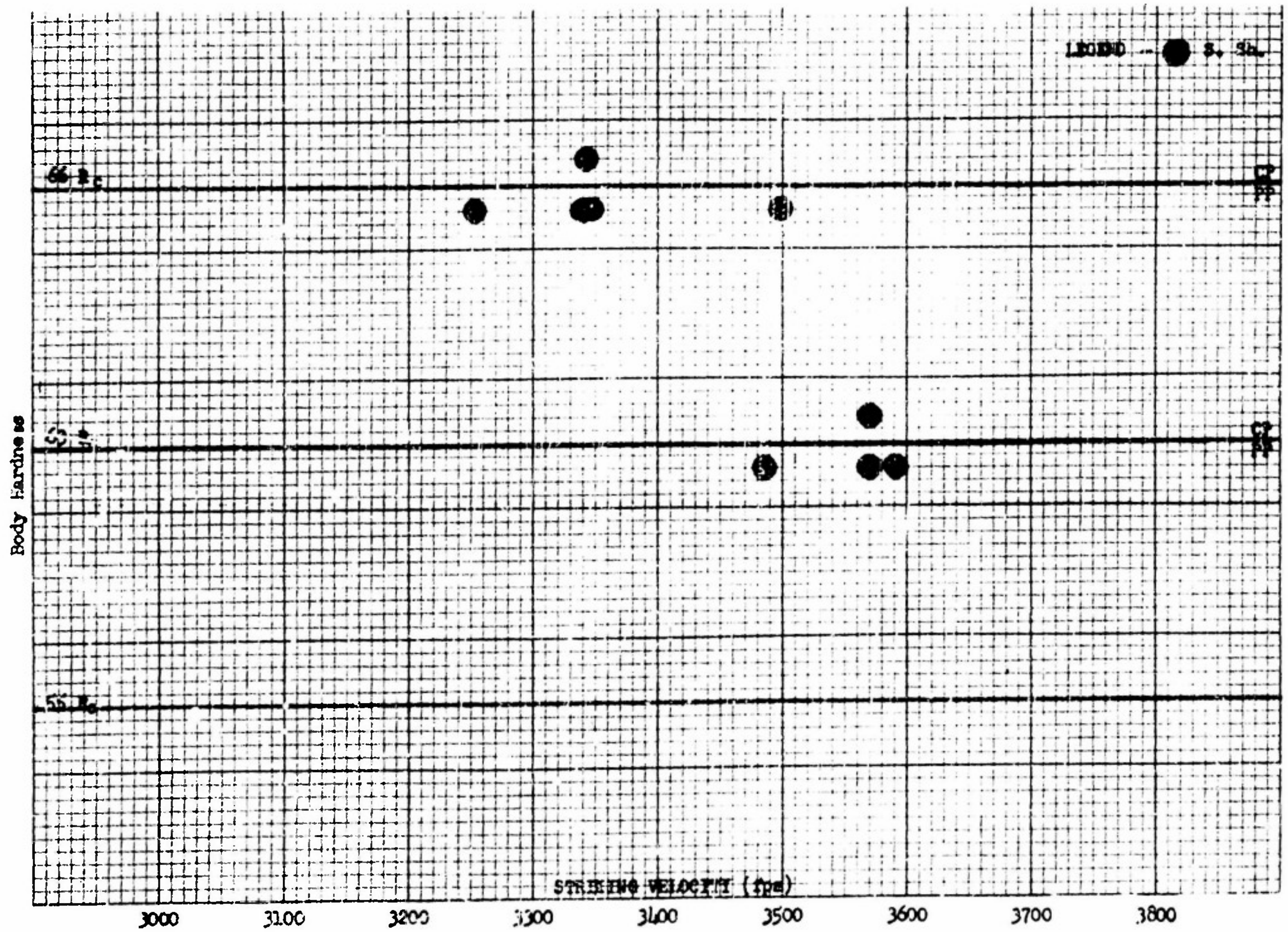

Figure 9. FAPT shot body hardness firings vs 7/8-inch homogeneous plate at 60° obliquity

Neg. #24754-10
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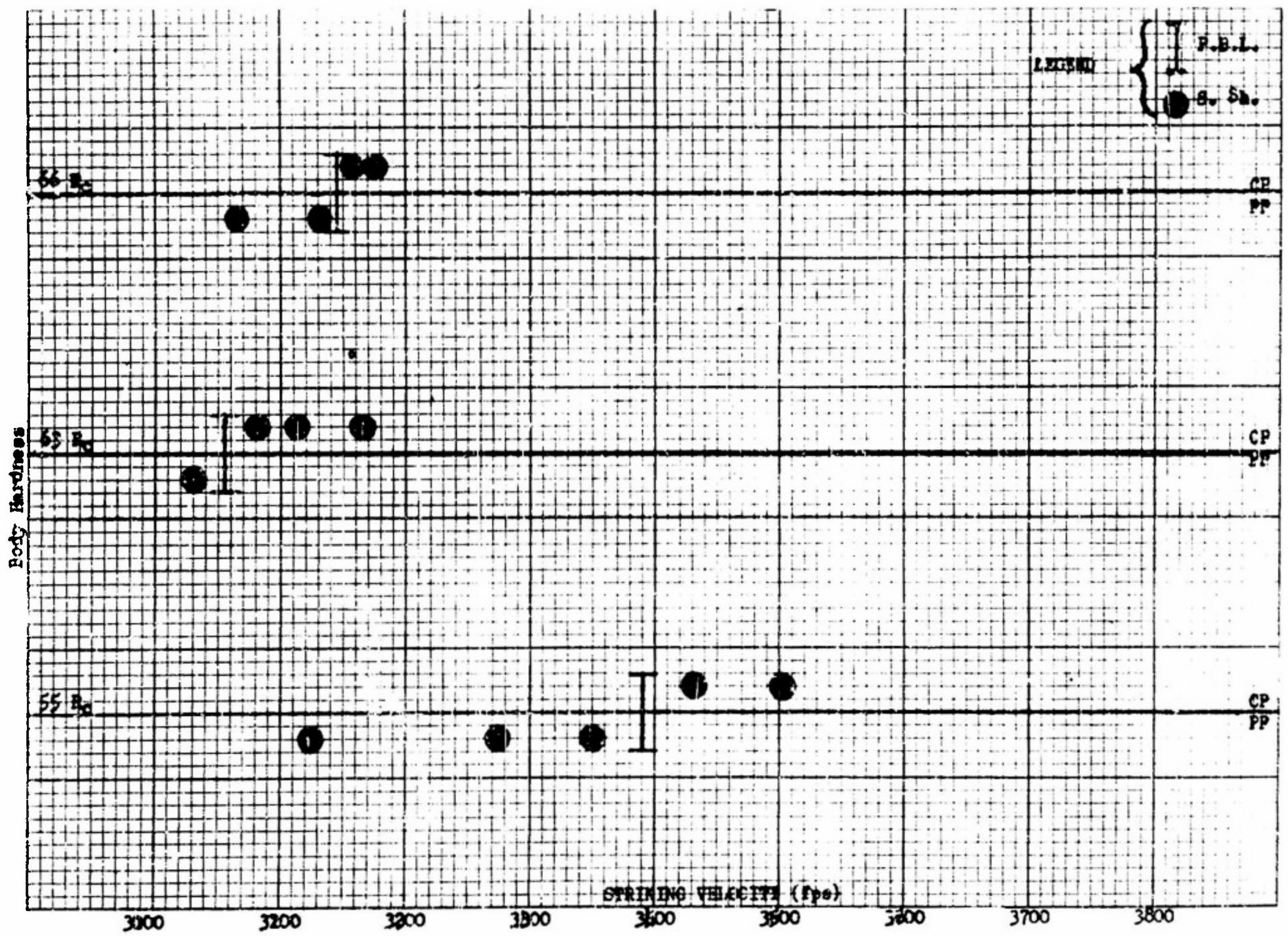

Figure 10. FAPT shot body hardness firings vs 7/8-inch homogeneous plate at 55° obliquity

Neg. #24754-11
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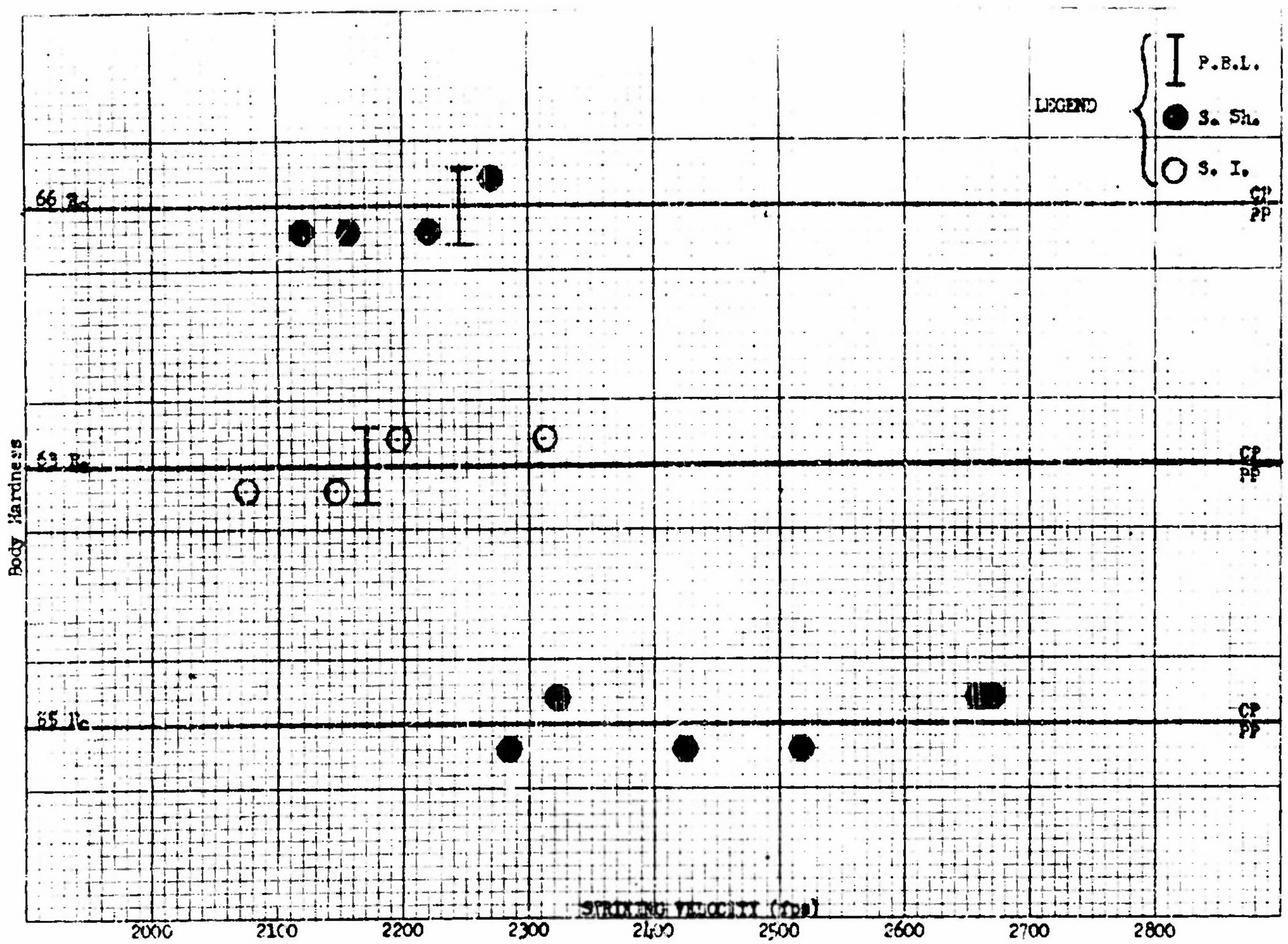

Figure 11. FAPT shot body hardness firings vs 7/8-inch homogeneous plate at 30° obliquity

Neg. #24754-12
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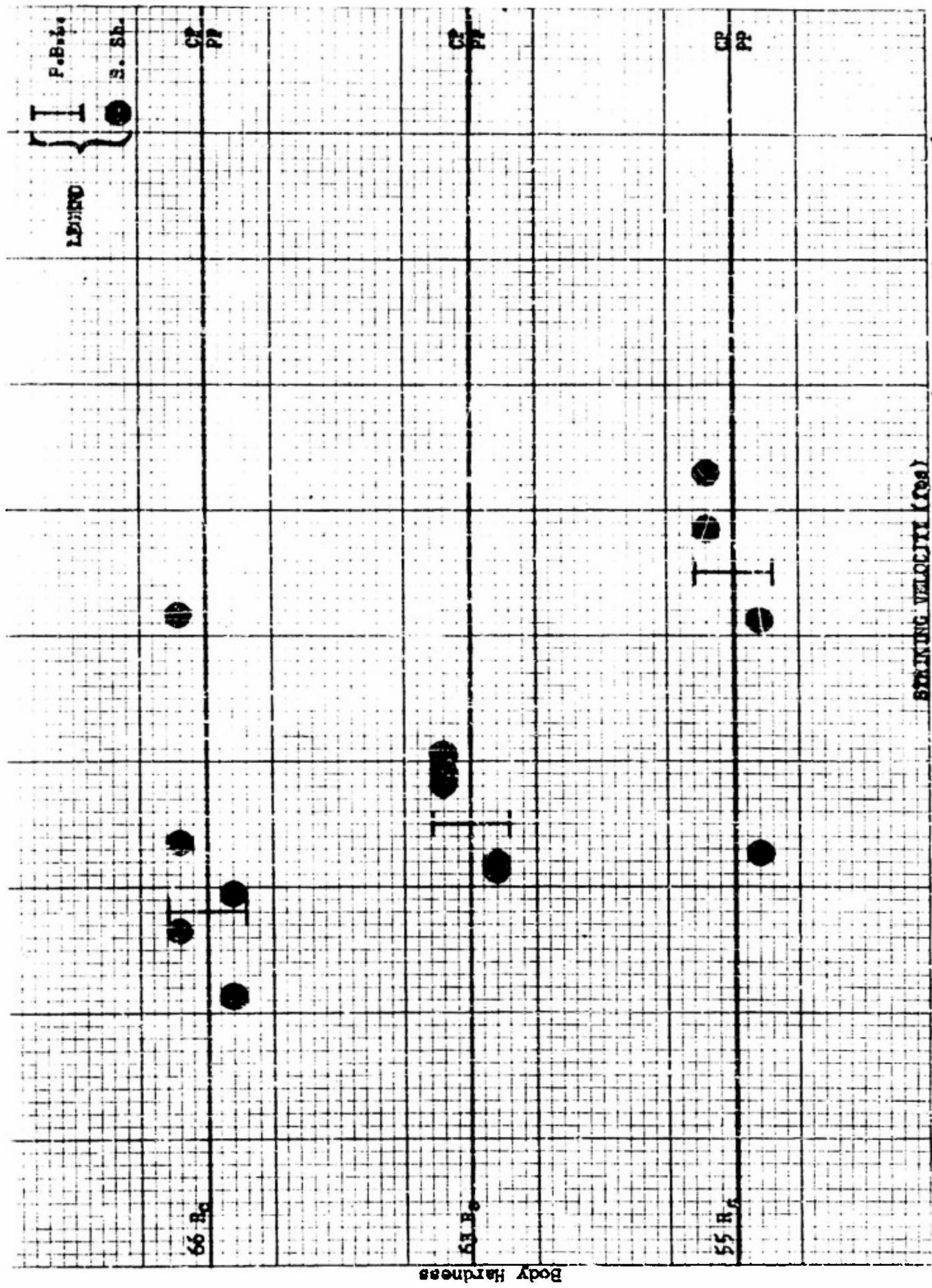

Figure 12. FAPT shot body hardness firings vs 3/4-inch homogeneous plate at 60° obliquity

Neg. #24754-13
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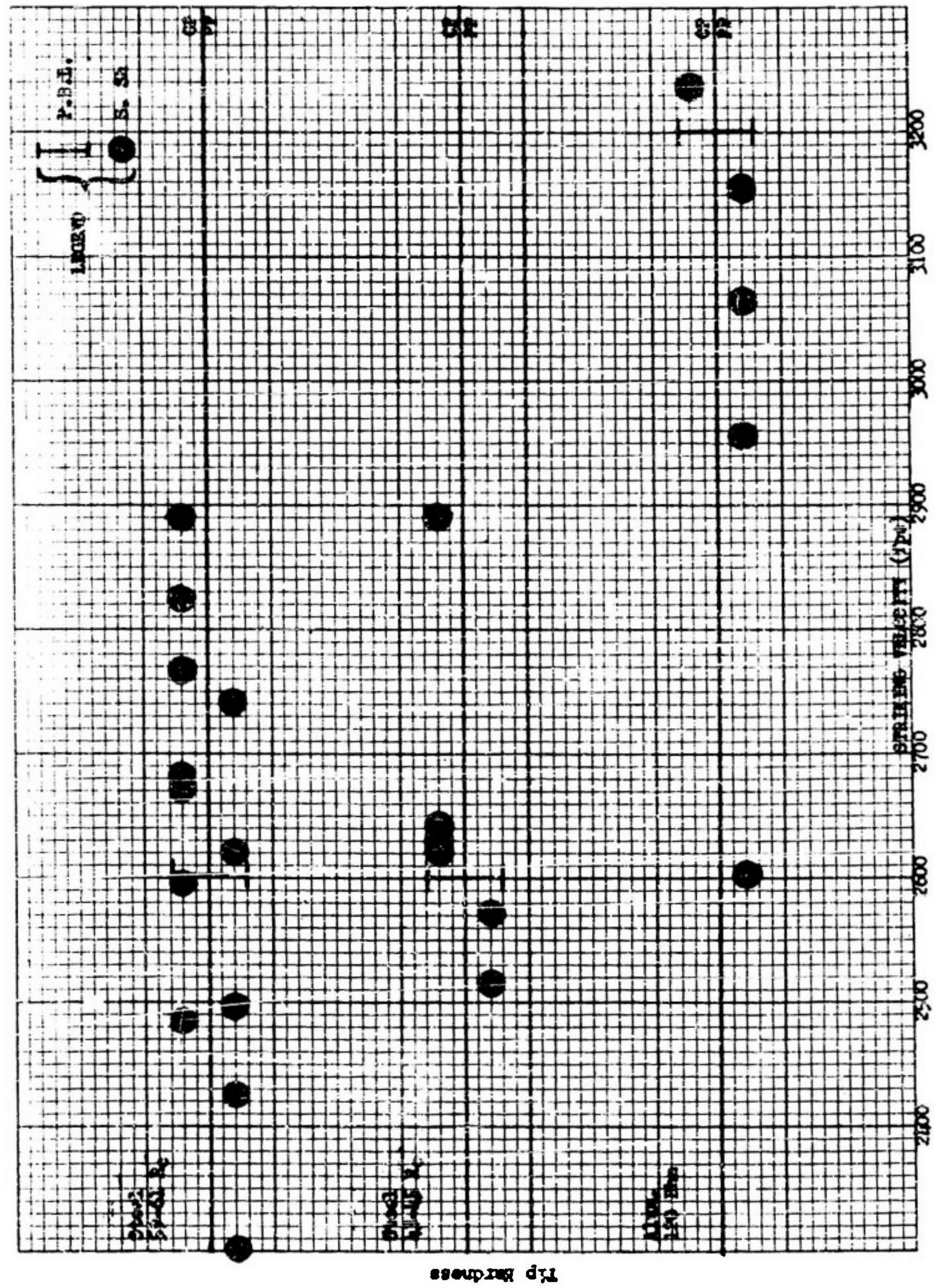

Figure 13. FAPT tip hardness f..ings vs 1-inch homogeneous plate at 30° obliquity

Neg. #24754-14
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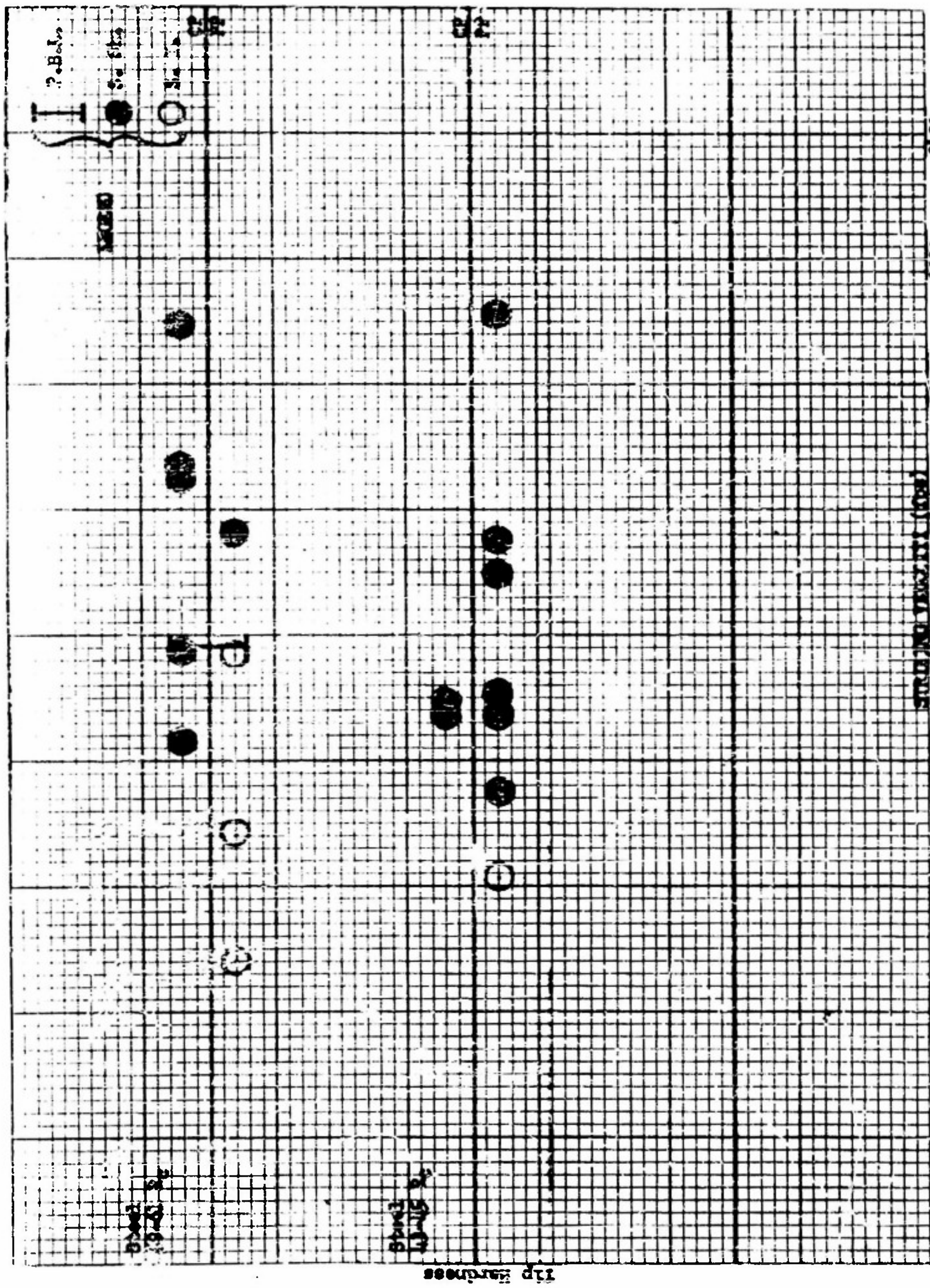

Figure 14. FAPT tip hardness firings vs 7/8-inch homogeneous plate at 55° obliquity

Neg. #24754-15
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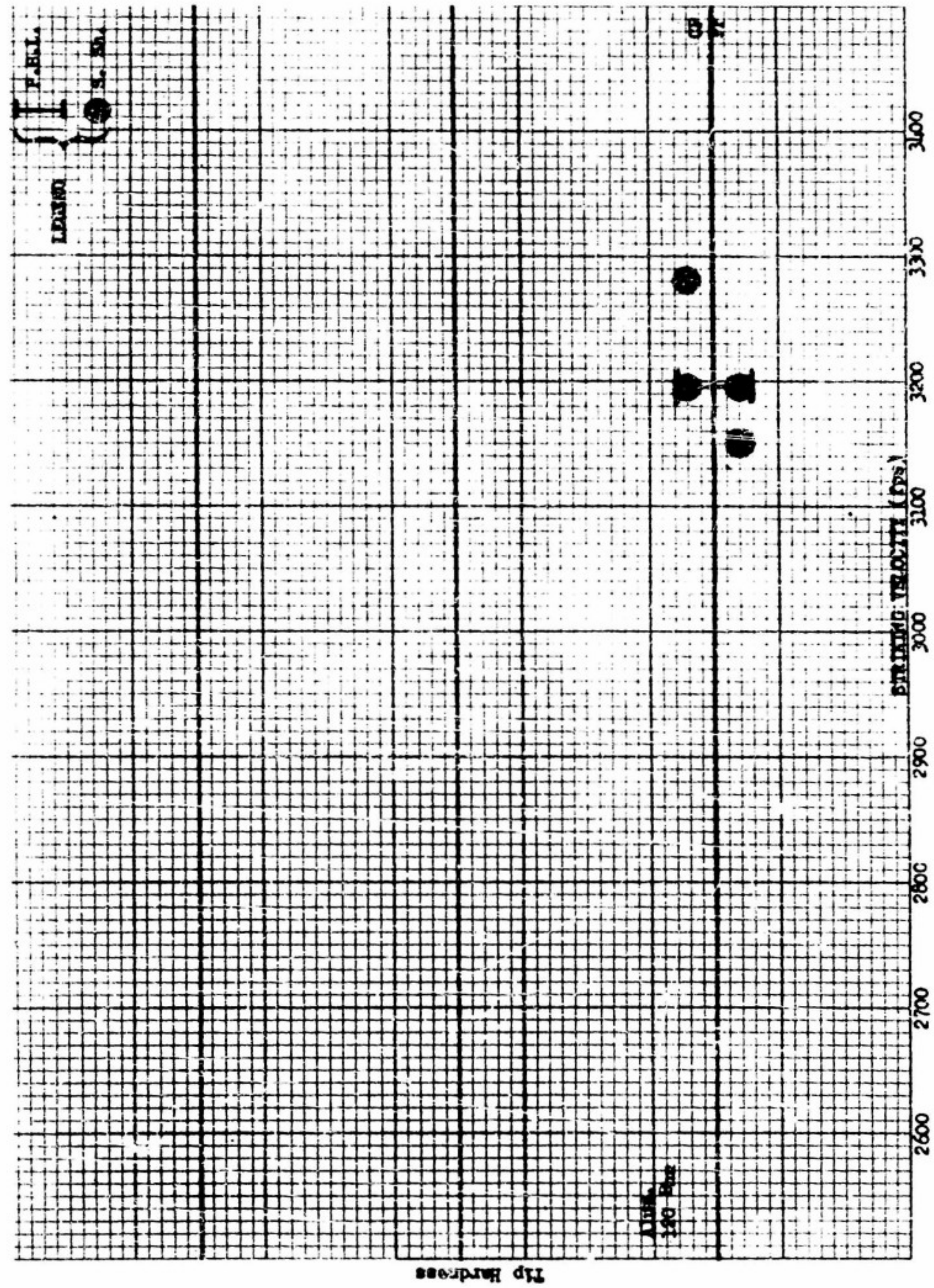

Figure 15. FAPT tip hardness firings vs 3/4-inch homogeneous plate at 60° obliquity

Neg. #24754-16
R-1189

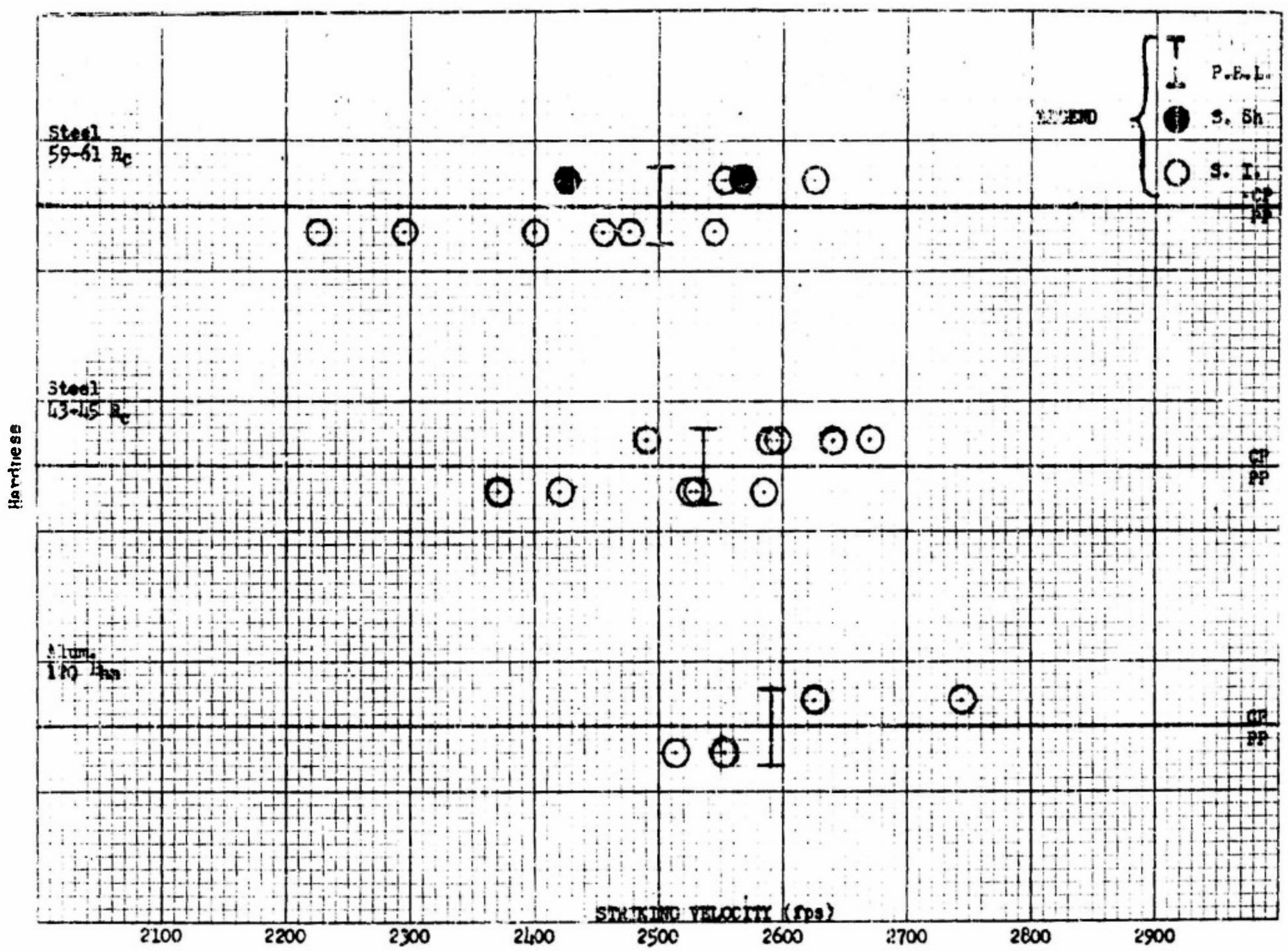

Figure 16. FAPT tip hardness firings vs 5/8-inch homogeneous plate at 60° obliquity

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